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Utilizing an In-Process Automatic Tool Change for Drilling and Reaming Large Diameter Holes

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ABSTRACT

A drill/ream cycle is necessary to produce high quality, large diameter holes in carbon-titanium stacks. Manual tool changes and traditional automatic tool changers limit hole-to-hole cycle times and hole quality. An in-process tool changer, mounted directly on the machine head, replaces a cutting tool with a reaming tool while clamp-up is maintained on the aircraft panel. By reducing or eliminating operator intervention, machine-axis moves, and optical resynchronization, an in-process automatic tool changer shortens cycle time, improves hole quality, and increases positional accuracy of holes. Automating this process also reduces risk of harm to the operator and aircraft structure.

INTRODUCTION

Automatic tool changers (ATC) are not new to the aerospace manufacturing community. They offer an automated process that has replaced manual tool changes in drilling machines. Although tool change automation provides faster cycle times, a traditional, floor-mounted ATC has significant limitations. An in-process automatic tool swapper (ATS) was developed for a next-generation post drilling machine operating on a CFRP/metallic outer wing box.

Traditional ATC's require that the machine unclamp from the work surface to make a tool change. This has several negative side effects to the overall drill/ream cycle. The machine axis moves associated with a traditional tool change increase cycle time. The loss of position on the panel requires resynchronization which decreases positional accuracy and repeatability of the machine head. Additionally, loss of position requires greater undersizing during the drill shot process, subsequently lengthening the reaming shot process and decreasing the accuracy and quality of the finished hole.

Today's aircraft designs require hole quality specifications which are hard to achieve. The drill/ream cycle times required to produce holes within specification are slow. Customer requirements for the lean technology drilling (LTD) machine dictated that no machine operator enter the drilling area while clamped on the aircraft panel. This requirement, along with the desired hole quality in CFRP/metallic stacks, led to the development of an in-process automatic tool changer. This paper describes the design, function, and benefits of an in-process tool change during a drill/ream cycle.

SYSTEM OVERVIEW

The LTD's automatic tool swapper replaces a cutting tool with a reaming tool. The ATS differs from a traditional automatic tool changer in that it provides space for only two tools. By limiting the number of stored tools, the ATS is able to remain compact and lightweight compared to a traditional ATC.

A major difference between the LTD ATS and a traditional ATC is that the ATS is able to perform tool change while machine clamp-up is maintained on the aircraft panel. The ATS is mounted on the clamp table to make use of the shuttle table axis (W_E) and spindle axis (W_S), thereby reducing the stroke necessary for the ATS to reach the drill spindle. Utilizing W_E and W_S minimizes the complexity and cost of the ATS. Hard indexing features are used to align the grippers in plane with the spindle centerline, eliminating the need for positional feedback and/or servo controlled axes.

Figure 1. LTD automatic tool swapper is shown with taper blow off.

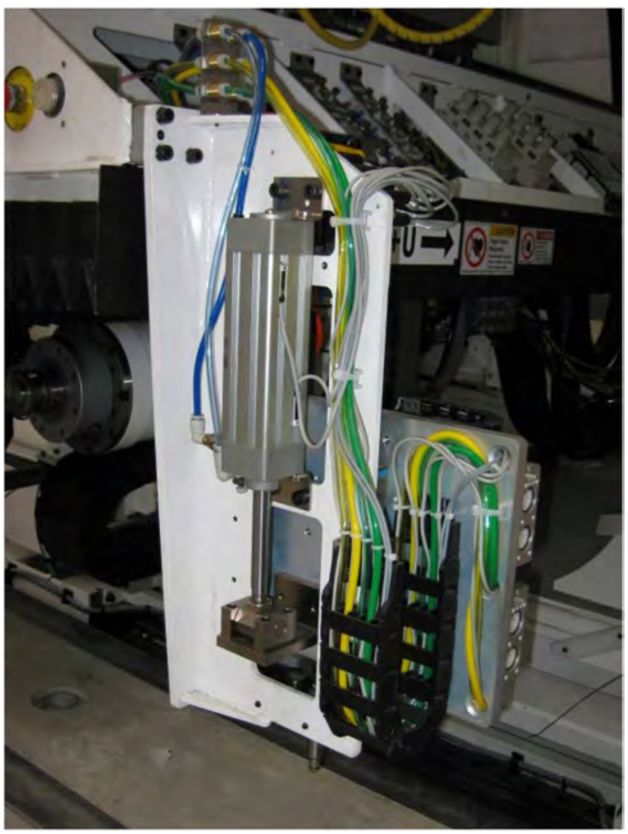

Figure 2. A two position air cylinder actuates to select gripper position.

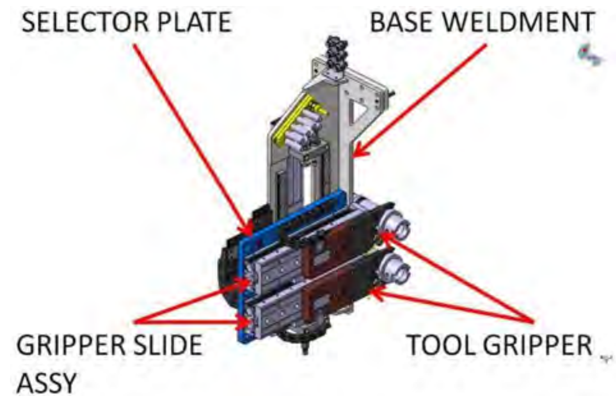

Figure 3. ATS components

Two gripper slide assemblies, mounted on the selector plate, include an air table and a single finger tool gripper. The tool gripper passively holds a 2.4 kg tool holder in place. Approximately 70 N, or over 20 g's acceleration, are required to pull the tool from the gripper.

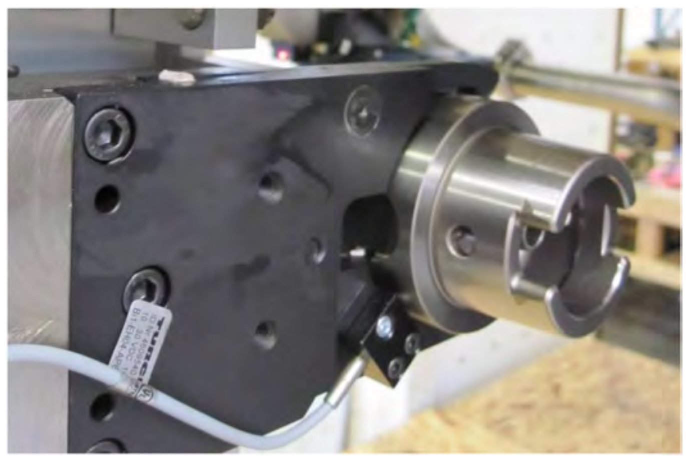

Figure 4. Single finger tool gripper shown with HSK 63A tool holder and proximity sensor.

TECHNICAL BENEFITS

The largest benefit the ATS provides is reduced hole-to-hole cycle time. This cycle time reduction results from the elimination of many machine axis moves traditionally associated with a manual tool change [1]. The ATS allows the LTD to remain clamped on the aircraft panel, which negates the need for any major machine axis moves. From drill to ream, the ATS offers a tool change that takes less than 20 seconds. For comparison, a manual tool change would take 360 seconds. The ATS saves over 5 minutes of cycle time over a manual tool change.

To safely enter the drilling zone during a manual tool change, the CNC must command a feed hold that pauses the drilling and fastening cycle. The ATS eliminates the feed hold command, further reducing the overall cycle time.

The ATS eliminates the need for an optical resynchronization. In previous systems where clamp-up is lost, a high resolution camera is used to locate existing hole features [2]. The ATS removes the need to unclamp from the panel for a manual tool change; therefore the LTD never loses position on the aircraft structure. This feature is the greatest advantage the ATS holds over traditional ATC's. Resynchronization is never completely repeatable, and the ATS allows the machine to hold true position on each hole during the entire drill/ream cycle.

The ATS allows much greater positional accuracy and repeatability on each hole because all machine axes moves and resynchronization processes are not needed [3]. These increases in positional accuracy allow a reduction in material removal during the reaming process. Drill/ream cycles that use feature resynchronization cut hole diameters undersized 1/32″ from nominal. By using an in-process tool change, the LTD is able to cut hole diameters undersized by only 1/64″ from nominal. This drastically improves hole quality and diametrical tolerances without having to increase the spindle size. The ATS effectively removes 200 lbs. from the process head by allowing use of a 173mm spindle cartridge opposed to a 205mm cartridge [3]. This reduction in material removal shortens the reaming cycle time by half [4].

ACCESS AND SAFETY BENEFITS

During drilling and other processes, machine operators should never enter the drilling zone. A feed hold command is necessary for a manual tool change because operator interaction with the drill spindle is required. Each pause in the overall process adds to the hole-to-hole cycle time. The ATS allows the operator to reduce the amount of time spent within the drilling zone, making the LTD machine faster and inherently safer to operate.

Reducing operator interaction with machine tools decreases other various health and safety risks. By automating a tool change, the ATS greatly reduces operator contact with sharp edges and machine coolant. It also alleviates ergonomic lifting concerns associated with a manual tool change.

Typically a manual tool change occurs at ground level for ease of operator access. It is possible to manually change a tool at height by using mobile access platforms or steps, but this causes many safety concerns. A manual tool change at height would require a larger exclusion zone to reduce the risk of dropped tools striking workers. The ATS eliminates any need for manual tool changes at height.

Whether at height or at floor level, a manual tool change introduces unnecessary hazards. Dropping tools is a risk associated with a manual process. A dropped cutter could cause harm to the operator or aircraft panel. Broken cutters are expensive to replace. The automated process provided by the ATS reduces the number of manual tool changes needed during machine operation.

MULTI-DIAMETER DRILLING BENEFITS

The ATS also offers benefits beyond drill/ream applications and safety. Small diameter drilling often does not require a ream cycle. During small diameter drilling on the aircraft panel, the ATS is able to change between different diameter cutters. Process dependent tooling is matched across the most common hole diameters, maximizing overall cycle efficiency [3].

This freedom in multi-diameter programming can drastically reduce the overall number of manual tool changes required during an entire part build. The ATS is able to accept any two tools and can easily and quickly change between them. ATS proximity sensors along with the LTD tool ID reader allow accurate CNC tool tracking.

ATS OPERATION SEQUENCE

After the LTD spindle finishes a drill cycle on the aircraft panel, the ATS swap process begins. The initial step of the tool swap process is a tool ID read. The tool ID is recorded to the CNC as each tool is loaded into the ATS grippers.

The empty gripper then extends as the spindle (W_S) moves in plane with the gripper (Figure 5). The shuttle table (W_E) then moves the cutter into the open gripper (Figure 6). A proximity switch detects if the tool is fully seated in the gripper (Figure 4). The drawbar releases the tool from the spindle. The spindle (W_S) retracts an additional 45mm to clear HSK taper from the extended drawbar fingers.

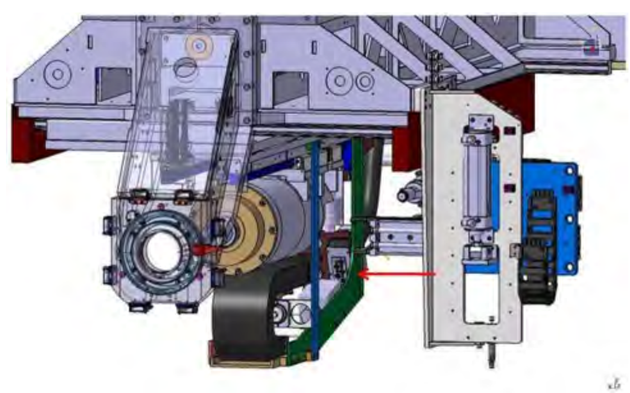

Figure 5. First gripper extends to receive tool from spindle.

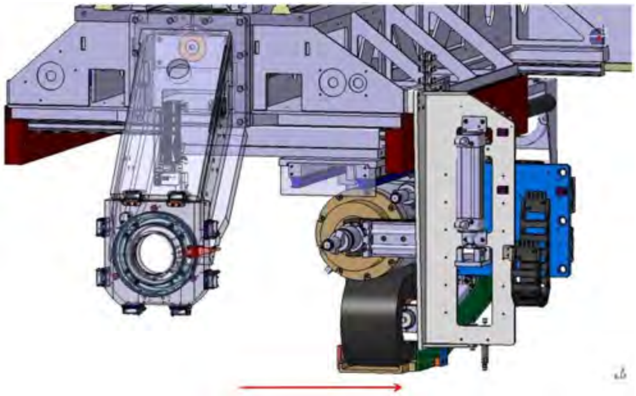

Figure 6. Shuttle movement loads cutter into Position 2 gripper.

After the drawbar fingers clear the HSK taper, the ATS taper blast activates (Figure 7). The gripper arm then retracts (Figure 8), moving the taper through the blast air, clearing any debris that may have accumulated on the cutting tool taper.

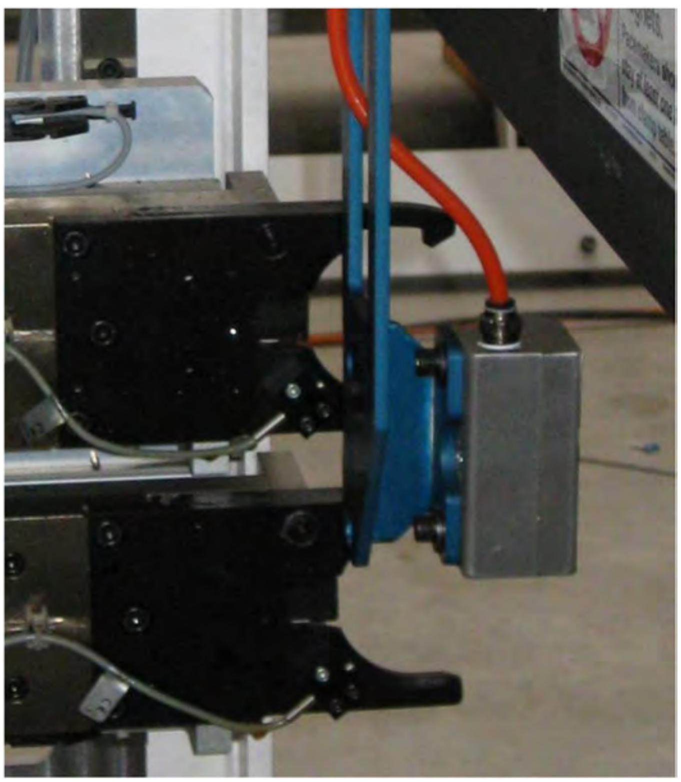

Figure 7. Taper blast clears debris from tool holders.

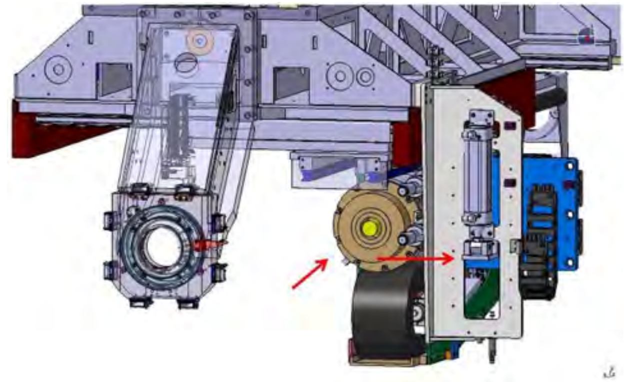

Figure 8. First gripper retracts to clear spindle.

The ATS selector plate now moves to the alternate gripper position that holds the reamer (Figure 9). This motion is limited by hard indexing features.

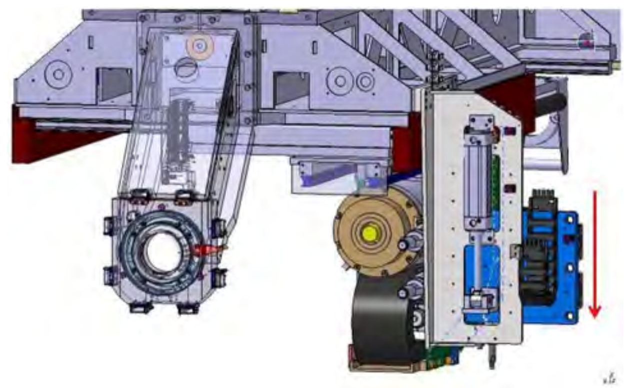

Figure 9. ATS selector plate shuttles to alternate position.

Taper blast activates again as the tool gripper extends to the spindle. When the gripper arm is fully extended (Figure 10), the spindle (W_S) drives forward over the HSK tool taper. The drawbar pump turns off and the shuttle table (W_E) moves away from the ATS with the fully seated reaming tool (Figure 11).

After the spindle has moved away from the ATS, the LTD reaming cycle begins on the aircraft panel. This process is repeated to swap the reaming tool with the cutting tool to begin another drilling cycle.

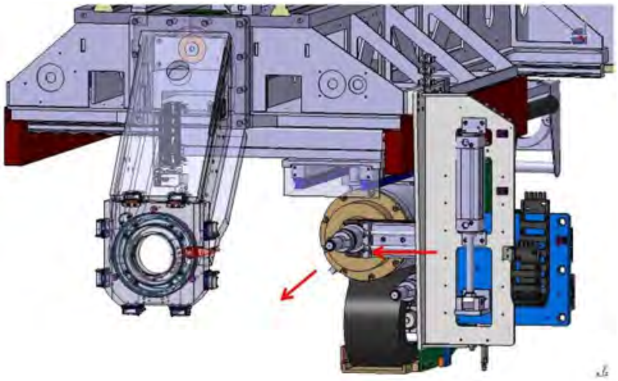

Figure 10. Second gripper extends to place new tool in spindle.

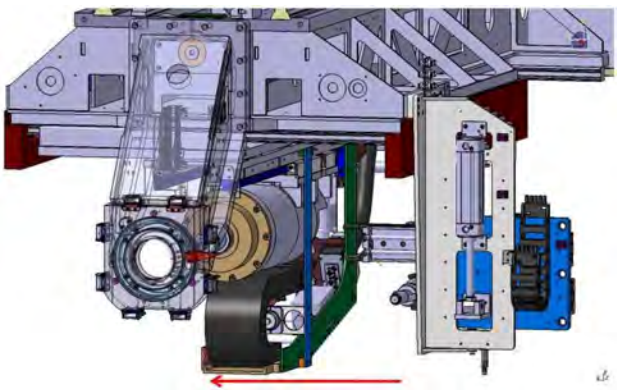

Figure 11. Shuttle movement unloads cutter from Position 1 gripper.

SUMMARY/CONCLUSIONS

The in-process tool change provided by the ATS permits the LTD machine to drill and ream holes more quickly than previous systems. The reductions in hole-to-hole cycle times are gained through a reduction of machine axis moves, elimination of mid-cycle resynchronization, and a dramatic reduction of operator involvement. The holes produced by the LTD enjoy tighter diametrical tolerancing, more repeatable and accurate positioning, and a higher quality surface finish. Use of standard purchased parts gives the ATS a robust design and reliable functionality. The ATS has many technical and health benefits and is an excellent tool to use with any machine performing drill/ream functions.

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CONTACT INFORMATION

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DEFINITIONS/ABBREVIATIONS

ATC
Automatic Tool Changer

ATS
Automatic Tool Swapper

CFRP
Carbon Fiber Reinforced Plastic

Clamp Table
Machine component that directs clamp load to panel.

CNC
Computer Numerical Control

LTD
Lean Technology Drilling

Shuttle Table
Machine component that holds process tools under the clamp table.

U
Clamp Axis

W_E
Shuttle Table Axis

W_S
Spindle Drive Axis

APPENDIX

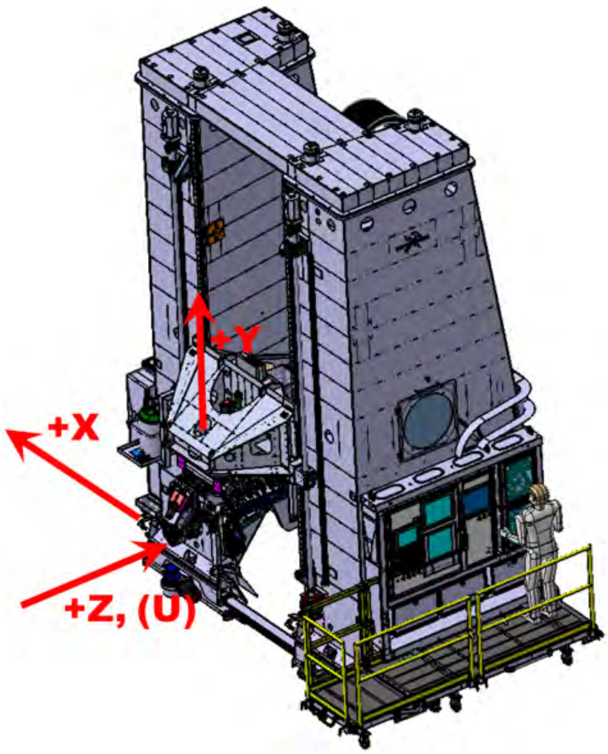

Figure 12. LTD shown with labeled major machine axes.

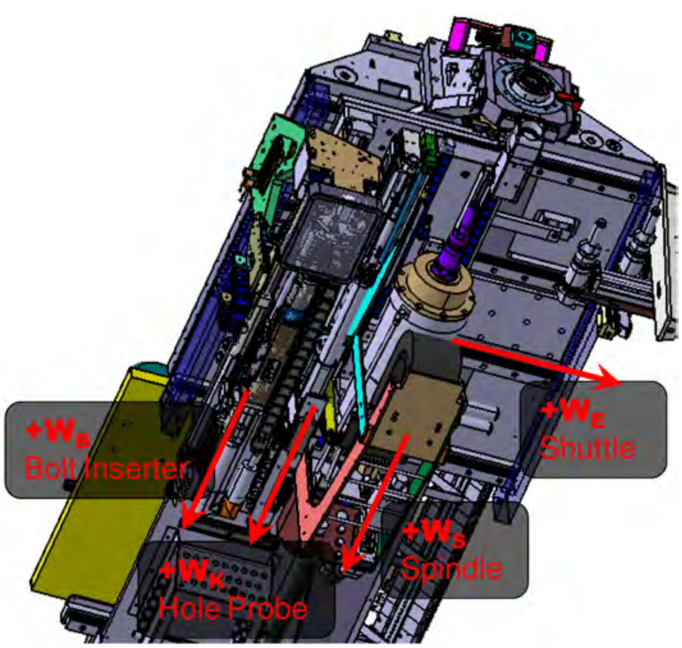

Figure 13. LTD process head with labeled process tool axes.

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